A BROAD RANGE AND HIGH RESOLUTION OPTICAL DISPERSION MEASUREMENT TECHNOLOGY
(Summary)

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Abstract – A novel dispersion measurement technology is proposed, which can be used to measure dispersion symbol and dispersion range from about 2 ps/nm to thousands ps/nm with the resolution of 0.27 ps/nm. Measurement limitation and error analysis are given.

1. Introduction

The chromatic dispersion is a critical parameter of optical elements and its characterization is essential for most optical systems. There are several methods for dispersion measurement, but the modulation phase-shift method [1] and the differential phase-shift method [2] are used by fiber manufacturers. However, both of these approaches are quite complex for most optical fiber end users. The AM method [3] is significantly less complex, but is limited to a minimum measurable dispersion of larger than 160 ps/nm; it also cannot be used for dispersion symbol measurement.

Here we present a novel measurement technique that can be used to measure the dispersion symbol and has a measurement range from about 2 ps/nm to several thousands ps/nm, with a 0.27 ps/nm or higher resolution. This technique is based on a differential measurement, and is similar to the AM method. It is thus simple, and easy to implement by the end user of optical components.

2. Measurement Principle and Setup

The measurement setup is shown in Fig. 1, where a laser was used as the light source and an optical spectrum analyzer was used to monitor the laser wavelength. The light component analyzer (LCA) generated a scanning RF signal to modulate the light, which passed through a "buffer" and the device under test (DUT), and back to LCA for spectrum analysis.

An amplitude modulated (AM) signal with small AM index m can be expressed as:

$$E(t,z) = E_0 \cdot [\cos(\omega_0 t - \beta_0 z) + 0.5m[\cos((\omega_0 + \omega_m)t - \beta_+ z) + \cos((\omega_0 - \omega_m)t - \beta_- z)]] \quad (1)$$

When such a signal is passed through a non-zero dispersion media with the length of L, the first order modulation frequency component of the photodetector output can be described as

$$v_m(t) = V_0 \cdot m \cdot \cos(0.5\beta_2 L \omega_m^2) \cdot \cos(\omega_m t) \cdot \exp(-j\beta_1 L \omega_m) \quad (2)$$

This frequency will be zero periodically when $\beta_2 L \omega_m^2 = (2n-1)\pi$, so the total dispersion is

$$D_T = (2n-1)c/(2\lambda^2 f_n^2) \quad (3)$$

where f_n is the modulation frequency for the nth zero point of RF output on the photodetector. We can get the total dispersion of DUT by measuring f_n at a given wavelength.

However, the lower measurable end of the AM method is limited by the higher end of the modulation frequency (from Eq.3). For a measurement system with the maximum modulation frequency of 20 GHz and a laser with 1550nm wavelength, the minimum measurable dispersion is about 160 ps/nm. If we introduce an additional device with more than 170 ps/nm dispersion as a buffer, it will expend the lower measurable end close to zero dispersion. In our measurement setup (Fig.1), we used a 12 km single mode fiber and a fiber grating as the buffers. Both of them reduced the minimum measurable value of the dispersion of the DUT to about 2 ps/nm.

We cannot get the dispersion symbol directly from Eq.3. However, it can be determined very easily by inserting the buffer. From Fig.1, the total dispersion may be expressed as

$$D_T = D_B + D_{DUT} = (2n-1)c/(2\lambda^2 f_n^2) \qquad (4)$$

where D_B and D_{DUT} are dispersions of the buffer and the DUT, respectively. Based on known D_B, the symbol can be determined by measuring the change of f_n. For small dispersion, we can use the following expression to get the dispersion directly:

$$dD_T = -2D_T df_n / f_n. \qquad (5)$$

The measurement resolution is dependent on the noise performance of the whole measurement system and the LCA resolution. If we take D_T as 200 ps/nm, f_n as 20 GHz, and the resolution of LCA as 1 MHz, we can get a resolution of about 0.02 ps/nm.

3. Measurement Results and Discussion

<u>System Calibration</u>   Since a single mode fiber is used as the buffer, its own dispersion performance has to be measured first. We used a 1548.48 nm DFB laser as the light source. The AM response for this measurement is shown in Fig. 2. With the length of 12.668 km and the first dip frequency point of 17.16 GHz (Fig. 2(b)), the total dispersion D_T and unit length dispersion D are 212.44 ps/nm and 16.77 ps/nm*km, respectively. For dispersion slop S measurement, we changed the laser wavelength to 1552.76 nm. The first dip frequency point moved to 16.97 GHz (shown in Fig. 3). So the dispersion slop of the buffer fiber is 0.066 ps/nm^2*km.

Dispersion Measurement

a) <u>1.14 km SMF</u>   A 1.14 km single mode fiber was placed as the DUT of Fig.1 for dispersion measurement. The dip frequency can be obtained from Fig.4 as 16.42 GHz. That means the total dispersion and unit length dispersion are 19.58 ps/nm and 17.17 ps/nm*km, respectively, as obtained from Eq. 7.

b) <u>Fiber grating</u> Since the dispersion of our grating is more than 180 ps/nm, we can directly measure the dispersion performance (without the buffer fiber). The frequency response is shown in Fig.5. From Fig.5(b), we can get the dip frequency of 16.70 GHz. So the dispersion is 224.19 ps/nm according to Eq.7.

We connected the grating with the buffer fiber (with +212.44 ps/nm dispersion). The total system AM response is shown in Fig.6. The dip frequency was much higher than 20 GHz, which means the grating has negative dispersion. The dispersion value should be –224.19 ps/nm.

c) <u>Small dispersion</u> A piece of single mode fiber with the length of 107 m was used as DUT, and the grating was used as the buffer. The dip frequency is about 16.77GHz (from Fig.7). Therefore the total dispersion and unit length dispersion are +1.87 ps/nm and +17.46 ps/nm*km.

Measurement Resolution

From Figs.2, 3, and 4, the measurement resolution is within 50 MHz, corresponding to a measurement error of less than 1.4 ps/nm. However, the data from Figs.5 and 7 can be obtained with a resolution better than 10 MHz, which makes the error less than 0.27 ps/nm (from Eq.5).

4. Conclusions

A novel dispersion measurement technique is proposed and demonstrated. The achieved minimum measurable dispersion can reach 1.87 ps/nm with the resolution of 0.27 ps/nm. The maximum of measured dispersion was more 230 ps/nm with the resolution of 1.4 ps/nm. The dispersion symbol and slope were also measured by the proposed measurement system.

References

1. B.Costa,D.Mazzoni,M.Puleo,and E.Vezzoni, IEEE J Quantum Electron,QE-18,p.1509,1982.
2. TIA/EIA FOTP-175, Washington DC, Telecommunications Industry Association, 1992.
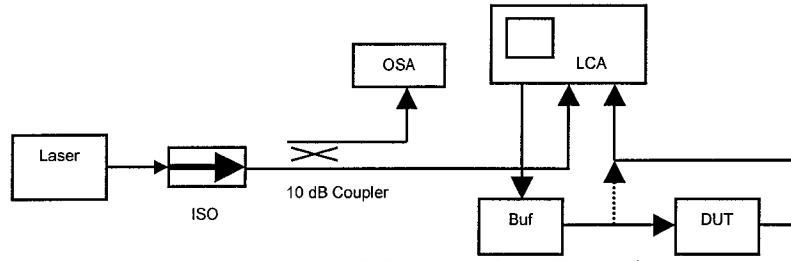3. B. Christensen, J. Mark, G. Jacobsen, and E. Bodtker, Electron. Lett., vol. 29, p.132, 1993.

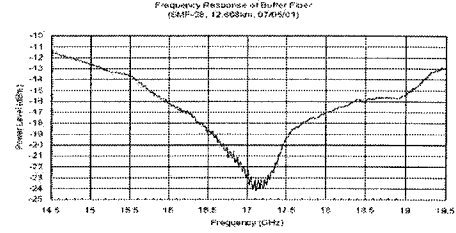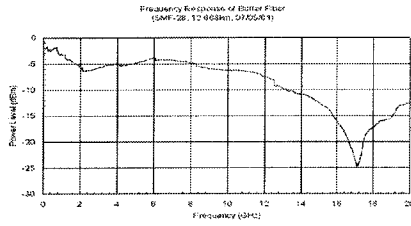Fig.1 Setup for broad range high resolution dispersion measurement.

Fig.2 AM response of buffer fiber. (a) full range;(b) near to dip frequency (λ_C=1548.48 nm).
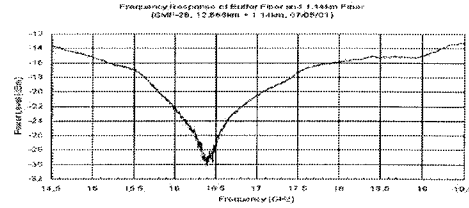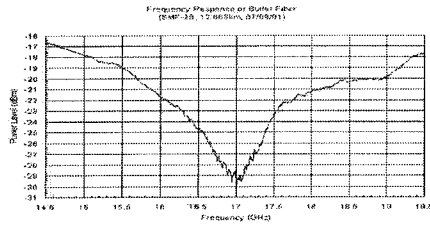

Fig.3 AM response of buffer fiber near to dip frequency (λ_C = 1552.76 nm).

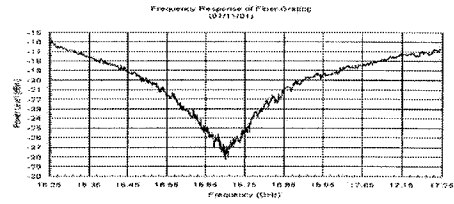Fig.4 AM frequency response of buffer fiber and 1.14 km SMF near to dip frequency.
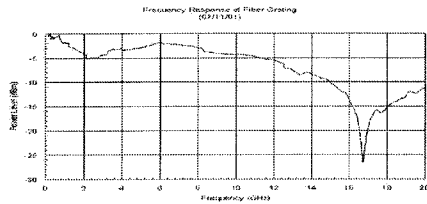

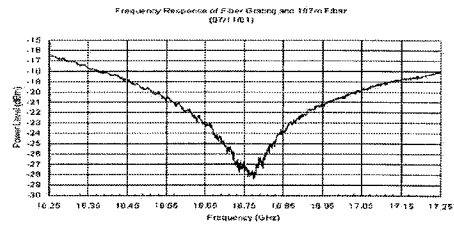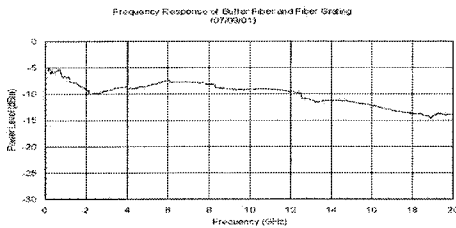Fig.5 AM response of fiber grating. (a) Full range; (b) near to dip frequency point.

Fig.6 Full range AM response of buffer grating and 107 m single mode fiber.

Fig.7 AM response of SMF and fiber grating, near to dip frequency point.